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for

THERMAL SOLUTION FOR ELECTRONICS COOLING USING A HEAT PIPE IN COMBINATION WITH ACTIVE LOOP SOLUTION

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FIELD OF THE INVENTION

[0002] The present invention generally relates to the field of cooling computer systems. More particularly, an embodiment of the present invention relates to cooling electronic components in the computer systems using a combination of heat pipes and active loop cooling techniques.

BACKGROUND

[0003] Portable computer systems such as laptop or notebook computer systems are quickly gaining popularity because of their lightweight, increase in performance and decrease in cost. As more functions are integrated into these computer systems, heat becomes an important issue that needs to be addressed.

[0004] One technique for heat or thermal management may include reducing the performance of components in the computer system. These components may include, for example, the central processing unit (CPU) or processor, the graphics chipset, the display, etc. This may not be desirable because reducing the performance of the components may affect the user's experience. Accordingly, techniques are being developed to improve thermal management associated with utilizing faster components in portable computer systems.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] The invention is illustrated by way of example and not limitation in the figures of the accompanying drawings, in which like references indicate similar or identical elements, and in which:

[0006] **Figure 1** illustrates an exemplary block diagram of a computer system which may be utilized to implement embodiments of the present invention.

[0007] **Figure 2** illustrates an exemplary block diagram of an active cooling system, in accordance with one embodiment.

[0008] **Figure 3** is a block diagram illustrating an example of an active cooling system using liquid metal as a liquid coolant, in accordance with one embodiment.

[0009] **Figure 4** is a block diagram illustrating an example of using heat pipes with an active cooling system to cool heat generating devices, in accordance with one embodiment

[0010] **Figure 5** is a block diagram illustrating an example of using heat pipes with an active cooling system to cool multiple heat generating devices, in accordance with one embodiment.

[0011] **Figure 6** is an example of a flow diagram describing a process of cooling multiple hot spots in a system, in accordance with one embodiment.

DETAILED DESCRIPTION

[0012] For one embodiment, an apparatus and a method for cooling electronic components in a computer system using a combination of active cooling and heat pipe cooling is disclosed. Active cooling may include transporting a liquid coolant toward and away from a heat exchanger using a flow-enhancer device such as, for example, a pump. The heat exchanger may also be used to provide condensation for a heat pipe.

[0013] In the following detailed description of the present invention numerous specific details are set forth in order to provide a thorough understanding of the present invention. However, it will be apparent to one skilled in the art that the present invention may be practiced without these specific details. In other instances, well-known structures and devices are shown in block diagram form, rather than in detail, in order to avoid obscuring the present invention.

[0014] Reference in the specification to "one embodiment" or "an embodiment" means that a particular feature, structure, or characteristic described in connection with the embodiment is included in at least one embodiment of the invention. The appearances of the phrase "in one embodiment" in various places in the specification are not necessarily all referring to the same embodiment.

[0015] **Figure 1** illustrates an exemplary block diagram of a computer system 100 which may be utilized to implement embodiments of the present invention. Although not shown, the computer system 100 is envisioned to receive electrical power from a direct current (DC) source (e.g., a battery) and/or from an alternating current (AC) source (e.g., by connecting to an electrical

outlet). The computer system 100 includes a central processing unit (CPU) or processor 102 coupled to a bus 105. For one embodiment, the processor 102 may be a processor in the Pentium® family of processors including, for example, Pentium® IV processors, Intel's XScale processor, Intel's Pentium M Processors, etc. available from Intel Corporation of Santa Clara, California. Alternatively, other processors from other manufacturers may also be used.

[0016] The computer system 100 may also include chipset 107 coupled to the bus 105. The chipset 107 may include a memory control hub (MCH) 110. The MCH 110 may include a memory controller 112 that is coupled to a main memory 115. The main memory 115 may store data and sequences of instructions that are executed by the processor 102 or any other device included in the system 100. For one embodiment, the main memory 115 may include one or more of dynamic random access memory (DRAM), read-only memory (RAM), etc.

[0017] The MCH 110 may also include a graphics interface 113 coupled to a graphics accelerator 130. The graphics interface 113 may be coupled to the graphics accelerator 130 via an accelerated graphics port (AGP) that operates according to an AGP Specification Revision 2.0 interface developed by the Intel Corporation of Santa Clara, California. A display (not shown) may be coupled to the graphics interface 113. The MCH 110 may be coupled to an input/output control hub (ICH) 140 via a hub interface. The ICH 140 provides an interface to input/output (I/O) devices within the computer system 100. The ICH 140 may be coupled to a Peripheral Component Interconnect (PCI) bus adhering to a Specification Revision 2.1 bus developed by the PCI Special Interest Group of Portland, Oregon. Thus, the ICH 140 may include a PCI bridge 146 that

provides an interface to a PCI bus 142. The PCI bridge 146 may provide a data path between the CPU 102 and peripheral devices such as, for example, an audio device 150 and a disk drive 155. Although not shown, other devices may also be coupled to the PCI bus 142 and the ICH 140.

PUMPED LOOP ACTIVE COOLING

[0018] During the time when the system 100 is processing work, the processor 102, the chipset 107, and other devices in the system 100 may generate heat. **Figure 2** illustrates an exemplary block diagram of an active cooling component 200 in accordance with one embodiment. The active cooling component 200 may be referred to as a pumped loop active cooling. The pumped loop may be of two different kinds: single phase loop and two-phase loop. In the single phase loop, a colder liquid enters an attach block or a cold plate and a hotter liquid leaves it. There may be no phase change from liquid to vapor involved there. In the two-phase cooling approach, a nearly saturated liquid enters the attach block and within it some of the liquid changes phase to become vapor. A mixture of liquid and vapor leaves the attach block. A first phase is a liquid phase, and a second phase is a vapor phase. The active cooling component 200 may include three stages which are extraction, transport, and rejection, as illustrated in **Figure 2**.

[0019] The extraction stage may include an attach block 210 coupled to a inlet pipe 212 and an outlet pipe 208. The attach block 210 may be coupled to a heat-generating device 214 (e.g., processor 102) to extract heat from the heat generating device 214. The attach block 210 may be coupled to the heat-generating device 214 through a thermal interface material (TIM). For one embodiment, an evaporator (not shown) may be embodied in or as the attach

block 210. To enhance its functionality, the evaporator may have multiple channels. The evaporator may be physically attached to heat generating device 214 (e.g., through a thermal interface material).

[0020] The transport stage includes the inlet pipe 212 and the outlet pipe 215. The transport stage may further include a pump 220 which may be used to enhance pipe flow. The transport stage transfers the heat extracted from the extraction stage to the rejection stage. The pump 220 may be coupled to the inlet pipe 212. Alternatively, the pump 220 may be coupled to both the inlet pipe 212 and the outlet pipe 215. For one embodiment, a reciprocating flow device (not shown) may be utilized with the pump 220. This flow device may be converted into a unidirectional flow device via check-valves. The pump 220 may force the liquid coolant to go through an evaporator (not shown) coupled to the attach block 210. The liquid coolant may at least partially change phase (liquid to vapor) and a mixture of the liquid coolant and vapor exits the evaporator. This mixture is then transported toward the rejection stage. A power supply (e.g., high current, bipolar, and the like) may be needed to control the pump 220.

[0021] For one embodiment, the inlet pipe 212 and the outlet pipe 215 may be metallic pipes such as, for example, copper piping with brazed, welded, and/or soldered connections. This may help enhance rigidity and/or heat exchange. For one embodiment, the diameter of the inlet pipe 212 and the outlet pipe 215 may be about 3 mm. Other types of pipes suitable for heat transport such as, for example, plastic, resin, a combination thereof, and the like may also be utilized. In addition, the diameter of the inlet pipe 212 and the outlet pipe 215 may depend on the type of pipe and/or the fluid passing through the

pipe. For one embodiment, the internal surface structure of the inlet pipe 212 and the outlet pipe 215 may not be the same as the internal surface structure of a heat pipe as is typically used in cooling systems.

[0022] For one embodiment, the inlet pipe 212 may have lower plate to fluid resistance than heat pipe evaporative resistance. For one embodiment, the outlet pipe 215 may include micro-channels to achieve low plate to fluid resistance. The liquid coolant may be water, alcohol, glycol, an inert liquid, combinations thereof, surfactants, mixtures thereof, and the like. Surfactants are envisioned to reduce surface tension of the fluid (even in minute amounts). For one embodiment, when the liquid coolant is water, the temperature of the liquid coolant may be at about 70 degrees Celsius. Furthermore, the system pressure may be at about 4.52 PSI nominally (or at about 0.31 Bar) with about one to two PSI difference through the channels. For example, the pressure may be at about 5 PSI at the pump 220, at about 6 PSI prior to entering the attach block 210, and at about 4.5 PSI upon exiting the attach block 210. For one embodiment, there may be a need for additional pressure drops at other locations to ensure flow stability.

[0023] For one embodiment, the inlet pipe 212 and the outlet pipe 215 of the pumped loop active cooling component 200 may form a closed loop to limit effects of outside pressure change such as, for example, when the system 100 is used at a high altitude.

[0024] The rejection stage may include a heat exchanger 202. The heat exchanger 202 may include a fan 204 to provide higher airflow. Heated air 206

may be rejected by the fan 204 into the ambient air. During the rejection stage, the liquid coolant may convert from the second phase (vapor) to the first phase (liquid). For one embodiment, the rejection stage may be physically placed at an outer edge or remote from the extraction stage to provide more efficient cooling. When the heat exchanger 202 is placed remotely from the attach block 210 or the heat generating device 214, the heat exchanger 202 may also be referred to as a remote heat exchanger (RHE). For one embodiment, the routing of the components of the transport stage (e.g., the outlet pipe 215 and the pump 220) may be proximate to non-heat generating devices and/or devices less susceptible to temperature changes.

[0025] Although not shown, the pumped loop active cooling component 200 may include a fill port for refill purpose in case of loss of liquid coolant through, for example, evaporation and/or for servicing the system. The pumped loop active cooling component 200 may also include, for example, a flow meter to measure fluid flow through the pump 220, an accumulator to regulate system pressure, one or more temperature probes to monitor the temperature of the pumped loop active cooling component 200 at various stages, etc.

<u>LIQUID-METAL ACTIVE COOLING</u>

[0026] **Figure 3** is a block diagram illustrating an example of an active cooling component using liquid metal as a liquid coolant, in accordance with one embodiment. The active cooling component 300 may be referred to as a liquid metal active cooling system and may include an attach block or attach block 310 which may be attached to a heat generating device 311. In this example, the liquid metal active cooling component 300 may include pipes 322 and 324 coupled to the attach block 310. The pipes 322, 324 may be implemented using

a rigid and flexible material. The rigidity and flexibility properties of the pipe material may enable the pipes 322, 324 to be easily routed around other devices inside, for example, the system 100. This may also enable the liquid metal active cooling component 300 to be implemented with an RHE 330 placed at a distance from the attach block 310. For one embodiment, the pipe material may be thermally conductive. For example, the pipes 322, 324 may be metal tubes, although other types of materials that allow heated liquid metal coolant to flow through may also be used. It may be noted that the pipes 322, 324 may not be heat pipes as is typically used in cooling systems.

[0027] The RHE 330 may include a fan 332 which creates air flow. The RHE 130 may include fins 331. The fan 332 may be mounted directly to the fins 331, or it may be positioned next to the fins 331. To enhance the flow of the liquid metal coolant between the attach block 310 and the RHE 330, pump 320 may be used. The pump 320 may be a mechanical pump or an electromagnetic pump. For example, the pump 320 may be a conduction pump, induction pump, centrifugal pump, regenerative turbo pump, magneto-hydrodynamics (MHD) pump, prezo-electrical pump, etc, as known to one skilled in the art.

[0028] The pump 320 may be used with the pipe 322 or both pipes 322 and 324. In the example illustrated in **Figure 3**, the pipe 322 is one that transports cooled liquid metal coolant from the direction of the RHE 130, and the pipe 324 is one that transports hot liquid metal coolant from the direction of the attach block 310. Liquid metal coolant typically has high thermal conductivity property, and thus may enable it to easily extract the heat generated by the heat generating device 311. The liquid metal coolant may be of a type that has low

freezing point (liquid to solid) and high boiling point (liquid to gas) properties. For one embodiment, the freezing point may be -10 degrees Celsius or below. The boiling point may be very high (e.g., 2080 degrees Celsius or higher). This may enable the liquid metal active cooling component 300 to operate in various temperature conditions. For one embodiment, the liquid metal coolant may be Indium (In), Gallium (Ga), or a mixture of Indium and Gallium with trace amounts of other metals such as, for example, zinc, copper, etc. For another embodiment, the liquid metal coolant may not be toxic or susceptible to combustion. Liquid metal is known to one skilled in the art.

[0029] For one embodiment, the liquid metal active cooling component 300 may be a closed-loop system. This cooling technique may be referred to as pumped loop cooling. When in a closed loop, the liquid metal coolant circulates between the attach block 310 and the RHE 330 or between one area of the system 100 and another area of the system 100. Referring to the example illustrated in **Figure 3**, the pipe 322 and the pipe 324 may be part of the same loop that connects the attach block 310 and the RHE 330. The liquid metal coolant extracts heat from the heat generating device 311 and transfers the heat from the attach block 310 to the RHE 330 along the pipe 324. The heat may then be rejected from the liquid metal coolant at the RHE 330 into ambient air. Cooled liquid metal coolant may then flow from the RHE 330 back to the attach block 310 along the pipe 322. Although the current example describes the cooled liquid metal coolant flowing from the RHE 330 to the attach block 310 along the pipe 322 and the heated liquid metal coolant flowing from the attach block 310 to the RHE 330 along the pipe 324, one skilled in the art will recognize that the direction of flow may be reversed.

[0030] One skilled in the art may recognize that, other than the pumped loop and liquid metal active cooling components described above, other types of active cooling components that utilize a device to enhance the flow of the liquid coolant may also be used with embodiments of the present invention. For example, instead of using a pump, a compressor may be used to increase the temperature of the heat exchanger to a value higher than that of the fluid exiting the cold plate. In this embodiment, it may be necessary to have the compressor between the evaporator and the heat exchanger. Moreover, a throttle valve may also be required between the heat exchanger and the cold plate. The choice of the liquid coolant would depend upon a variety of thermo physical properties to obtain a good balance between the heat transfer properties (to reduce plate to fluid resistance) and compression ratio (to minimize energy consumed in the compressor).

HEAT PIPES WITH ACTIVE COOLING SYSTEMS

[0031] **Figure 4** is a block diagram illustrating an example of using heat pipes with an active cooling component to cool heat generating devices, in accordance with one embodiment. Cooling system 400 may include heat pipe 405. The heat pipe 405 may be considered a passive cooling component of the cooling system 400 because it does not utilize a pump. The heat pipe 405 may be a closed, evacuated cylindrical aluminum or copper vessel with internal walls lined with a capillary structure or wick that is saturated with a working fluid. The working fluid enters the pores of the wicking material, wetting all internal surfaces. Since the heat pipe 405 may be evacuated and then charged with the working fluid prior to being sealed, the internal pressure is set by the vapor pressure of the fluid. When the heat pipe 405 is coupled to a heat generating

device 410 that is coupled to the attach block 415, heat generated by the device enters the heat pipe 405 at an evaporation end, as illustrated in **Figure 4**. The heat causes the working fluid to vaporize. The vaporized fluid creates a pressure gradient, which forces the vapor to flow along the heat pipe 405 to a condensation end of the heat pipe 405. For one embodiment, the condensation end of the heat pipe 405 is coupled to heat exchanger 430 which enables the vapor to condense into the working liquid. The working fluid is then returned to the evaporation end of the heat pipe 405 by capillary forces developed in the wick structure.

[0032] For one embodiment, the cooling system 400 may also include an active cooling component. For another embodiment, the active cooling component may be the pumped loop cooling or the liquid metal cooling described above. Referring to **Figure 4**, the active cooling component may include pump 420, the heat exchanger 430, attach block 415, and pipe loop 420. The heat exchanger 430 may be an RHE and may include a fan 432 and fins 431. The heat exchanger 430 may be shared by both the passive cooling component and the active cooling component. For one embodiment, the heat exchanger 430 may be used to help condensing the vapor in the heat pipe 405 and in the pipe loop 420 when the active cooling component is the two-phase pumped loop cooling. For another embodiment, the heat exchanger 430 may be used to help condensing the vapor in the heat pipe 405 and cooling the liquid metal coolant in the pipe loop 420 when the active cooling component is liquid metal cooling. For another embodiment, the heat exchanger 430 may be used to help condensing the vapor in the heat pipe 405 and cooling the liquid in the pipe loop 420 when the active component is any other kind.

[0033] It may be noted that the pump 420 may be a type of pump that requires connection to a power supply to operate. This may increase the power consumption of the system 100 and may not be desirable especially when the system 100 is operating with a DC power supply (e.g., battery). In addition, noise may be generated when the pump 420 is in operation. One advantage of having both the passive cooling component and the active cooling component in the cooling system 400 is that cooling of the heat generating device 410 may continue even when power to the pump 420 is turned off. Turning off the power to the pump 420 may also reduce noise associated with the pump 420. Having the heat pipe as a passive cooling component may further dampen transient power conditions to which an active cooling component may be sensitive or simply cannot respond fast enough. One skilled in the art may recognize that although only one heat pipe 405 is described, additional heat pipes may also be used as part of the cooling system 400 to cool the heat generating device 410.

[0034] **Figure 5** is a block diagram illustrating an example of using heat pipes with an active cooling component to cool multiple heat generating devices, in accordance with one embodiment. In this example, cooling system 500 may include a passive cooling component and an active cooling component to cool heat generating devices 510 and 511.

[0035] For one embodiment, the passive cooling component of the cooling system 500 includes heat pipe 505 to cool the heat generating device 511. Similar to the heat pipes described above, the heat pipe 505 includes an evaporation end coupled to the heat generating device 511. The heat pipe 505

also includes a condensation end coupled to heat exchanger 530. The heat exchanger 530 may include a fan 532 and fins 531. The heat exchanger 530 may enable vapor in the heat pipe 505 to condense when the vapor reaches the condensation end.

[0036] For one embodiment, the active cooling component of the cooling system 500 may include pump 520, attach block 505, pipe loop 525, and the heat exchanger 530, and may be used to cool the heat generating device 510. The heat exchanger 530 may be shared with the heat pipe 505 of the passive cooling component of the cooling system 500. For one embodiment, the active cooling component of the cooling system 500 may be two-phase cooling or single phase cooling or liquid metal cooling as described above.

[0037] The cooling system 500 may be useful to provide multi-devices cooling. For example, the heat pipe 505 may relieve the complexity of having to route the pipe loop 525 to an additional device such as the device 511. Furthermore, by using the heat pipe 505 as a cooling solution for the device 511, design complexity or operational sensitivity of the active cooling component (e.g., two-phase cooling) may be reduced. In addition, using the heat pipe 505 as a cooling solution for the device 511 may enable a multi-hot spot solution at a lower cost, especially when the heat generated by the device 511 may not require the sophistication of an active cooling component such as, for example, two-phase or single phase or liquid metal cooling. One skilled in the art may recognize that the techniques described with the cooling system 400 in **Figure 4** and the cooling system 500 in **Figure 5** may be combined to provide more cooling flexibility.

[0038] **Figure 6** is an example of a flow diagram describing a process of cooling multiple hot spots in a system, in accordance with one embodiment. Each hot spot may be a heat generating device as described above. At block 605, an active cooling component is used to cool a first device. The active cooling component may use a pump to enhance the flow of the liquid coolant. At block 610, a test is performed to determine if a secondary cooling is necessary for the first device. If the secondary cooling is necessary, the process flows to block 615 where operations to apply a passive cooling component with the first device is performed. Otherwise, the process flows from block 610 to block 620 where a test is performed to determine if a there is a second device that needs cooling. If there is a second device, the process flows to block 625 where operations to apply a passive cooling component with the second device is performed. The process may be considered to be done at block 630.

[0039] From the above description and drawings, it will be understood by those of ordinary skill in the art that the particular embodiments shown and described are for purposes of illustration only and are not intended to limit the scope of the invention. Those of ordinary skill in the art will recognize that the invention may be embodied in other specific forms without departing from its spirit or essential characteristics. References to details of particular embodiments are not intended to limit the scope of the claims.